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(54) Capacitive Transducer

(57) A capacitive transducer comprises two plate electrodes 11, 12 Fig. 1a aligned along a main axis 17 and positioned in juxtaposed relationship on one surface of a dielectric substrate 14 Fig. 1d; and an array of segmented electrodes 13 Fig. 1c aligned in a direction transverse to the main axis 17 and provided on the opposite side of the substrate 14. Capacitive coupling is achieved between the segmented electrode array 13 and the two plate electrodes 11, 12. The

geometrics of the transducer (e.g. the segment lengths as shown, or their width in direction 17, or the thickness of substrate 14) are such that increasing capacitive coupling is obtained along the main axis of the transducer. An AC signal 15 supplied to one, 11, of the plate electrodes and detected by e.g. a resistor 16 connected to the other electrode 12, can be attenuated by physically touching the segmented electrode array 13. Attenuation can be varied by moving such physical contact along the main axis 17. One or more transducers can be used in a co-ordinate arrangement to provide an X—Y position indicating device.

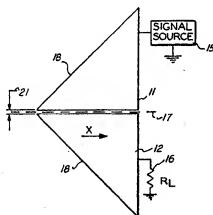


FIG. 1a

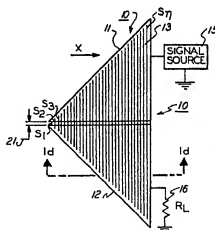


FIG. 1c

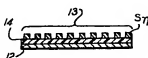


FIG. 1d

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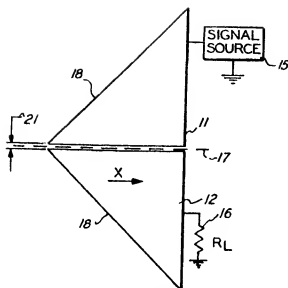


FIG. 1a

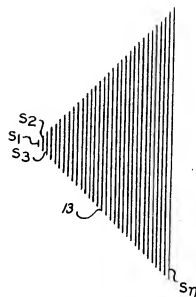


FIG. 1b

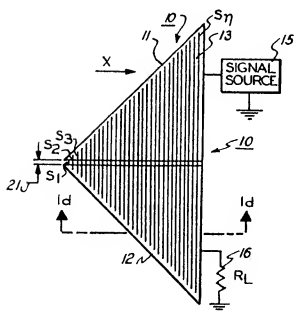


FIG. 1c

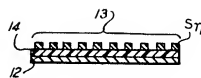
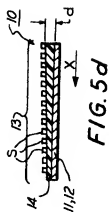
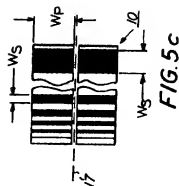
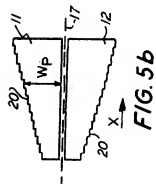
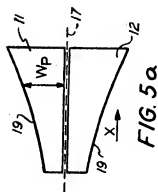
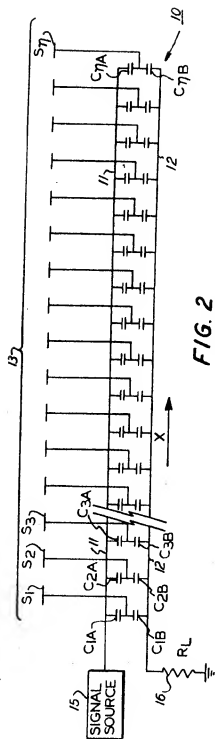
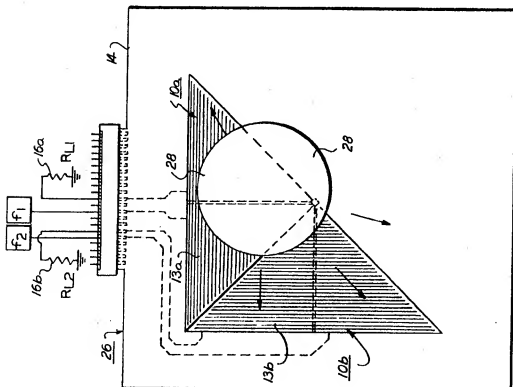


FIG. 1d





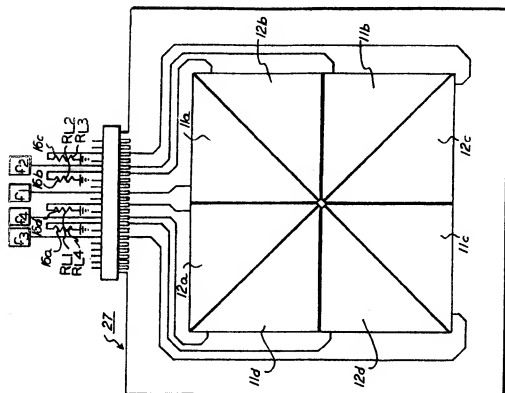


FIG. 4a

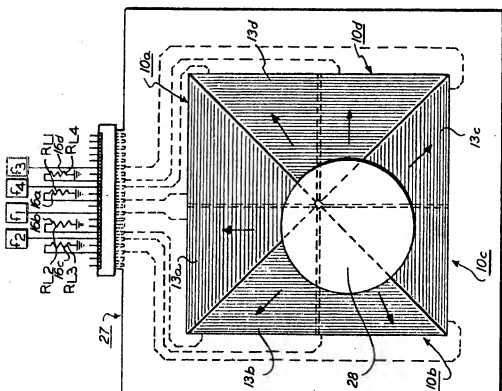


FIG. 4b

SPECIFICATION

Capacitive Transducers

This invention relates to capacitive transducers.

- 5 There are many types of transducers of the active type where the input to the transducer may be altered by other received stimuli at another input to produce an output from the transducer indicative of a change in a particular parameter.
- 10 For example, a potentiometer or rheostat may be used to electrically indicate a particular physical position relative to an X-Y co-ordinate system. The shaft encoder is another example of
- 15 mechanical transducer capable of indicating the position of one element relative to another element. A piezoelectric device can be used to electrically indicate the amount of pressure or weight applied to the device.
- 20 These control mechanisms employ moving parts which are susceptible to mechanical wear, inaccuracies due to transitional misalignments of component parts or inaccuracies due to mechanical limitations during transitional movement in a direction transverse to generally
- 25 designated cartesian co-ordinates. The employment of an electronic position indicating device would at least reduce, if not eliminate, the impact of these disadvantages.
- UK Specification 48775/77 filed 23 November
- 30 1977 discloses an electronic cursor positioning tablet having no moving parts where the physical contact of the operator's finger moving across the surface of the device provides co-ordinate information for movement of a cursor over a
- 35 visual display in a text editing system. This device functions on the principal of variable capacitance caused by finger movement on the surface of the device in proximity to a plurality of capacitor plates. This device does not employ moving
- 40 mechanical parts but requires sophisticated electronic circuitry for sensing the variance of capacitance to provide signal outputs representative of X-Y position co-ordinates.
- 45 In accordance with the invention, a capacitive transducer comprising at least two plate electrodes aligned along a main axis in spaced juxtaposed relation, an array of segmented electrodes aligned in a direction transverse to said main axis overlying said plate electrodes but
- 50 separated therefrom by dielectric means, said segmented electrodes capacitively coupled to said plate electrodes in an increasing capacitive and monotonic manner from one end of the transducer to the other along said main axis.
- 55 The plate electrodes may have a triangular configuration, that is, provided with a taper along two longitudinal edges thereof. However, the tapers may have parabolic or step function configuration.
- 60 One of the plate electrodes is preferably an input terminal to which a varying signal source is connected to provide an input signal. Detection means such as a load resistor is connected to the

- 65 attenuated by means (e.g. a finger) engageable with one or more segments of the electrode array and movable thereacross to shunt a portion of the input signal. The input signal, as attenuated, is detectable by the detection means.
- 70 At least a pair of capacitive transducers may be employed as a X-Y position indicator where the main axis of one of the transducers is parallel to the X axis of the orthogonal co-ordinates of the indicator and the main axis of the other of the
- 75 transducers is parallel to the Y axis of the orthogonal co-ordinates of the indicator.
- A transducer according to the invention will now be described by way of example with reference to the accompanying drawings, wherein:
- 80 Fig. 1 is a plan view of the bottom plate electrodes of the transducer;
- Fig. 1b, is a plan view of the array of top segmented electrodes of the transducer;
- 85 Fig. 1c, is a plan view of the assembled transducer;
- Fig. 1d, is an exaggerated sectional view of the transducer of Fig. 1c as seen from the plane indicated by the line 1d—1d of Fig. 1c;
- 90 Fig. 2, is an electrical equivalent of the transducer shown in Fig. 1c;
- Fig. 3a, is a plan view of two transducers employed in a touch panel configuration to function as an X-Y position indicator;
- 95 Fig. 3b is a bottom view of the panel of Fig. 3a;
- Fig. 4a is a plan view of four capacitive transducers employed in a quadrature touch panel configuration to function as an X-Y position indicator;
- 100 Fig. 4b is a bottom view of the panel of Fig. 4a;
- Fig. 5a is another possible taper configuration for the plate electrodes of Fig. 1a;
- Fig. 5b is still another possible taper configuration for the plate electrodes of Fig. 1a;
- 105 Fig. 5c is an exaggerated plan view of a modified version of the transducers of Fig. 1c wherein the segmented electrode comprises different width segments; and
- Fig. 5b is an exaggerated cross-sectional view showing another modified version of the transducer of Fig. 1c wherein the dielectric layer or substrate varies linearly along its length.
- Referring now to the drawings, in Fig. 1 there is shown the capacitive transducer 10. Transducer
- 110 10 comprises three principal parts, plate electrodes 11, 12 (Fig. 1a) an array of segmented electrodes 13 (Fig. 1b), and a dielectric layer or substrate 14 (Fig. 1d).
- The plate electrodes 11, 12 are conductive. As shown in Fig. 1a, the plate electrodes 11, 12 are arranged in spaced juxtaposed position along a main axis 17, i.e., separated by a spacing 21. One plate 11 represents an input terminal to the transducer 10 and is connected to AC signal source 15. The other plate 12 represents the output terminal and is connected to detection means 16, which is shown here as load resistor R.

plurality of conductive segments S_1 to S_n . As best shown in Fig. 1d, the segments S_n overlie the plate electrodes 11, 12 and are separated therefrom by the dielectric substrate 14.

The segmented electrode array 13 is capacitive coupled to the plate electrodes 11, 12. The application of an AC signal of known amplitude from source 15 to plate 11 will appear across resistor R_L . If a person touches the segmented electrode array 13, a portion of the applied AC signal would be shunted to ground via the body of the person. Because the human body has a large capacitance, signal shunting to ground is possible through the user's body capacitance. Of course the AC signal is of low magnitude so as not to be harmful to the user.

As noted in Figure 1a, the plates electrode 11, 12 each have a tapered edge 18. Because of this tapered configuration, the amount of attenuation upon finger contact can be selectively varied. The amount of signal shunting to ground depends upon the position of the finger contact along the main axis 17. Finger movement from left to right in Fig. 1c in the X direction will result in increasing capacitance and, therefore, increasing signal attenuation across resistor R_L . The increase in capacitance in the X direction is due to increase in plate electrode area because diverging tapers 18 as well as the increase in segment electrode area, because of their increase in length.

It should be noted that the taper 18 need be only provided along one edge of a plate electrode 11 or 12 to achieve this increasing capacitive coupling effect.

The increase capacitive coupling effect need not be derived only from the taper configuration of Fig. 1. As shown in Figs. 5a and 5b respectively, the taper configuration can be parabolic in nature as indicated at 19, or a step function, as indicated at 20. In any case, the increasing capacitive coupling in the X direction will be achieved as long as the taper configuration is monotonic, i.e., the taper increases continually in the X direction without again decreasing, whether the degree of tapering is linear or not.

In Fig. 2, an electrical equivalent of the transducer 10 is shown. C_{na} represents the capacitance between each individual segment S_n and plate electrode 11. C_{nb} represents the capacitance between each individual segment S_n and plate electrode 12. There is increasing capacitive coupling in the X direction for each individual segment S_n because the effective plate area represented by plate electrodes 11, 12 and each segment increases in the X direction. This is readily apparent from the equation:

$$C = kA \\ d$$

where A is the cross-sectional area of the electrodes of a capacitor, d is the dielectric thickness and k is a dielectric constant. Capacitance is therefore directly proportional to

electrode area. As electrode area increases, so does the capacitance.

The amount of signal attenuation to be obtained with transducer 10 depends upon both how many segments S_n are instantaneously touched and the physical location of the segments S_n touched along the X direction. Thus, upon viewing both Figs. 1c and 2, touch contact of one or more segments at the left end or portion of the transducer 10 will provide lower attenuation at the transducer output than touch contact at the right end or portion of the transducer.

Movement of one's finger from left to right in the X direction will produce increasing signal attenuation at the output as detected across load resistor R_L . The rate of attenuation developed by such movement depends on the rate of finger movement. The rate at which attenuation changes with finger movement from segment to segment depends on the slope of taper 18 of plate electrodes 11, 12 relative to the main axis 17. As previously indicated, the attenuation rate of change could be reduced by providing only one taper 18 per plate electrode set.

Movement of one's finger at a constant rate across the segmented electrode 13 in an X direction will provide linear, monotonic attenuation. Such finger movement where the taper configuration of Figs. 5a or 5b is employed will, respectively, provide parabolic or sinusoidal type of attenuation in a monotonic manner.

If a probe contact is employed rather than finger contact in connection with the transducer 10 in a manner that segments S_n beginning with segment S_1 are initially and continuously engaged in a cumulative manner and at a uniform rate in the X direction, the attenuation of the output signal would be parabolic and monotonic in nature. A hand held metal bar could be used to perform this probe contact function.

Reference up to this point has been made to different taper configurations for plate electrodes 11, 12 as shown in Figs. 1a, 5a, and 5b. However, there are other geometric variations of the transducer 10 by which attenuation can be achieved in the X direction or for providing attenuation to be a function of the distance along the main axis 17.

Figs. 1a, 5a and 5b represent the condition.

$$W_p = f(X),$$

where W_p is the width of a plate electrode 11 or 12 and X is the distance in the X direction. In this embodiment, the thickness d, of the dielectric substrate 14 and the width, W_s of the segments S are fixed.

Another geometric consideration is

$$w_s = f(X),$$

where the width of the segments S_n can be increased as a function of distance across the

illustration, the thickness, d , of the dielectric and the plate electrode width, W_p , are fixed.

A third geometric consideration is

$$d=f(X),$$

- 5 where the thickness of the dielectric substrate increases as a function of distance across the transducer as illustrated in Fig. 5d. In this illustration, the width, W_p , of the segments S_n and the width W_p of the plate electrodes 11, 12 are fixed. Thus, what is meant by "increasing capacitive coupling" is the built-in increase in capacitance obtained from one end of the transducers to the other end in the X direction by either providing tapered configuration, a change in dielectric thickness, or a change in electrode segment width, or possibly a combination of one or more of these variable geometric parameters.

- A transducer 10 can be made on a thin substrate 14 of Kapton (trademark) or Mylar (trademark) film which initially has copper cladding on both surfaces. A pattern of the pair of triangular plate electrodes 11, 12 are then etched into the copper cladding on one film surface while the array of electrode segments S_n is etched into the copper cladding on the other film surface.

- In Figs. 3 and 4, arrangements are shown for employing transducer 10 in an X-Y position indicator 28 and 27 respectively. In Fig. 3 two transducers 10a and 10b are employed while in Fig. 4 four transducers 10a, 10b, 10c and 10d are employed. The operation of these two embodiments is basically the same except that in Fig. 3 only one transducer is employed to produce a signal representative of the X or Y co-ordinate positions whereas in Fig. 4 two transducers are employed to identify the X or Y co-ordinate positions. This latter arrangement is preferred from the standpoint of accuracy because a difference signal can be derived which is more precise as to exact position in a Cartesian co-ordinate system.

- For purpose of explanation, simultaneous reference will be made to both Figs. 3 and 4 since indicator 27 of Fig. 4 is a multiple variation of indicator 26 of Figure 3, like elements having the same reference numerals. As shown in Figs. 3a and 4a, the substrate 14 is provided, respectively, with two and four transducers 10a, 10b, 10c and 10d, having segmented electrode arrays 13a, 13b, 13c and 13d. Transducers 10a and 10c are positioned on the Y co-ordinate while transducers 10b and 10d are positioned on the X co-ordinate. These co-ordinates are aligned with the main axis 17 of each of the transducers as discussed in connection with Fig. 1.

- The plate electrodes 11, 12 are respectively provided for each of the transducers 10a, 10b, 10c and 10d. As shown in Figs. 3b and 4b, input terminal plate electrodes 11a, 11b, 11c and 11d are, respectively, connected to AC signal sources f_1, f_2, f_3 and f_4 . Output terminal plate electrodes 12a, 12b, 12c and 12d are connected to

- 16d. Signal sources f_1, f_2, f_3 and f_4 may be of the same frequency. However, to improve performance as an X-Y position indicator, each signal source may have a different signal frequency. Any undesirable coupling between adjacent transducers can be filtered out and reliable co-ordinate values established by determining the difference in signal value (amplitude) between oppositely opposed quadrature transducers 10a and 10c or 10b and 10d in Figure 4 or by the individual signal value for the co-ordinate transducers 10a or 10b in Fig. 3.

- A conductive probe contact 28 is used to operate the X-Y position indicators 28, 27. The contact 28 may be moved about the surfaces of the segment electrodes with the index finger, for example, providing simultaneous engagement with more than one co-ordinate transducer. As shown in Fig. 3a, the diameter of the disk type contact 28 is equal to the height of the equilateral triangle formed by the segment electrode arrays 13. The contact 28 may be moved to either completely cover a particular array or not cover the array at 11, not even one electrode segment of a particular array.

- Movement in any direction of the contact 28 will cover and contact a selected number of segments S_n of one or more segmented electrode arrays. The amount of segment electrode coverage in any quadrant will shunt to ground a proportional amount of the AC signal supplied to the respective transducer indicative of the position of the contact 28 relative to an X-Y co-ordinate system in the plane of substrate 14. The central position for co-ordinates would be the centre of contact 28 in Figures 3a and 3b.

- A transducer of the present invention was fabricated from copper clad polyimide 0.001 inch thick. The transducer consisted of the triangular pattern depicted in Figure 1. The copper electrodes of the transducers were formed by acid etching. The segments, S_n of the segmented electrode array were each 0.015 inch wide and separated from each other by 0.005 inch. The distance from the central apex of each segmented electrode array to its base was 2 inches. The input terminal plate electrode of the transducer was connected to a pulse generator to supply a 100 KHz signal. The output terminal plate electrode was connected to a 1 megohm load resistor. The resulting waveforms caused by finger contact on the segmented electrodes were examined by an oscilloscope connected across the load resistor. The output signal could be smoothly attenuated in a linear manner in the X direction from 0% to 20% by continuous finger movement from the transducer apex to the widest end of the transducer.

Claims

1. A capacitive transducer comprising at least two plate electrodes aligned along a main axis in spaced juxtaposed relation, an array of

transverse to said main axis overlying said plate electrodes but separated therefrom by dielectric means, said segmented electrodes capacitively coupled to said plate electrodes in an increasing capacitive and monotonic manner from one end of the transducer to the other along said main axis.

2. The transducer of Claim 1 wherein said plate electrodes are of triangular shaped configuration.

3. The transducer of Claim 2 wherein said segmented electrode array has the configuration of said plate electrodes.

4. The transducer of Claim 1 wherein one of said plate electrodes is an input terminal, a varying signal source is connected to said input terminal to provide an input signal and means engageable with one or more of said segment electrodes is movable thereacross to shunt a portion of said input signal.

5. The transducer of Claim 4 wherein a detection means is connected to the other said plate electrodes and said attenuated input signal is arranged to be detected by said detection means.

6. The transducer of Claim 5 wherein said detection means is a load resistor.

7. The transducer of Claim 1 wherein said plate electrodes are provided with a taper along one edge thereof.

8. The transducer of Claim 7 wherein said taper is parabolic.

9. The transducer of Claim 7 wherein said taper is a step function.

10. The transducer of Claim 7 wherein said taper is linear and is disposed at an acute angle relative to said main axis.

11. The transducer of Claim 1 wherein the segments comprising said electrode array are elongated stripes having narrow and identical widths.

12. The transducer of Claim 11 wherein the width of said segment is greater than the distance of separation of said segments.

13. The transducer of Claim 1 wherein the segments comprising said electrode array are elongated stripes having narrow widths and the widths of said segments are of increasing magnitude from one end of the array to the other.

14. The transducer of Claim 1 wherein the thickness of said dielectric means is of increasing magnitude from one end of the transducer to the other along said main axis.

15. The transducer as claimed in Claim 1 for use as an X-Y position indicator comprising at least two transducers the main axis of one of said transducers parallel to the X axis of a co-ordinate system and the other of said transducers parallel to the Y axis of the same co-ordinate system.

16. Transducers substantially as hereinbefore described with reference to the accompanying drawings.